# New Acoustic Wave Pipe Inspection System

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# Project Description

- **Flaw Detection**
  - **Modeling**
  - **EMAT Flaw set-up**
  - **Data analysis**
- **Leak Detection**
  - **Microcantilever sensor**
  - **Experimental set-up**

# Advantages of the approach

- Non contact sensor
- Ability to detect all flaws in one pass
- Ability to reduce data collected, thus reducing processing time
- Integrate flaw and leak detection in one system

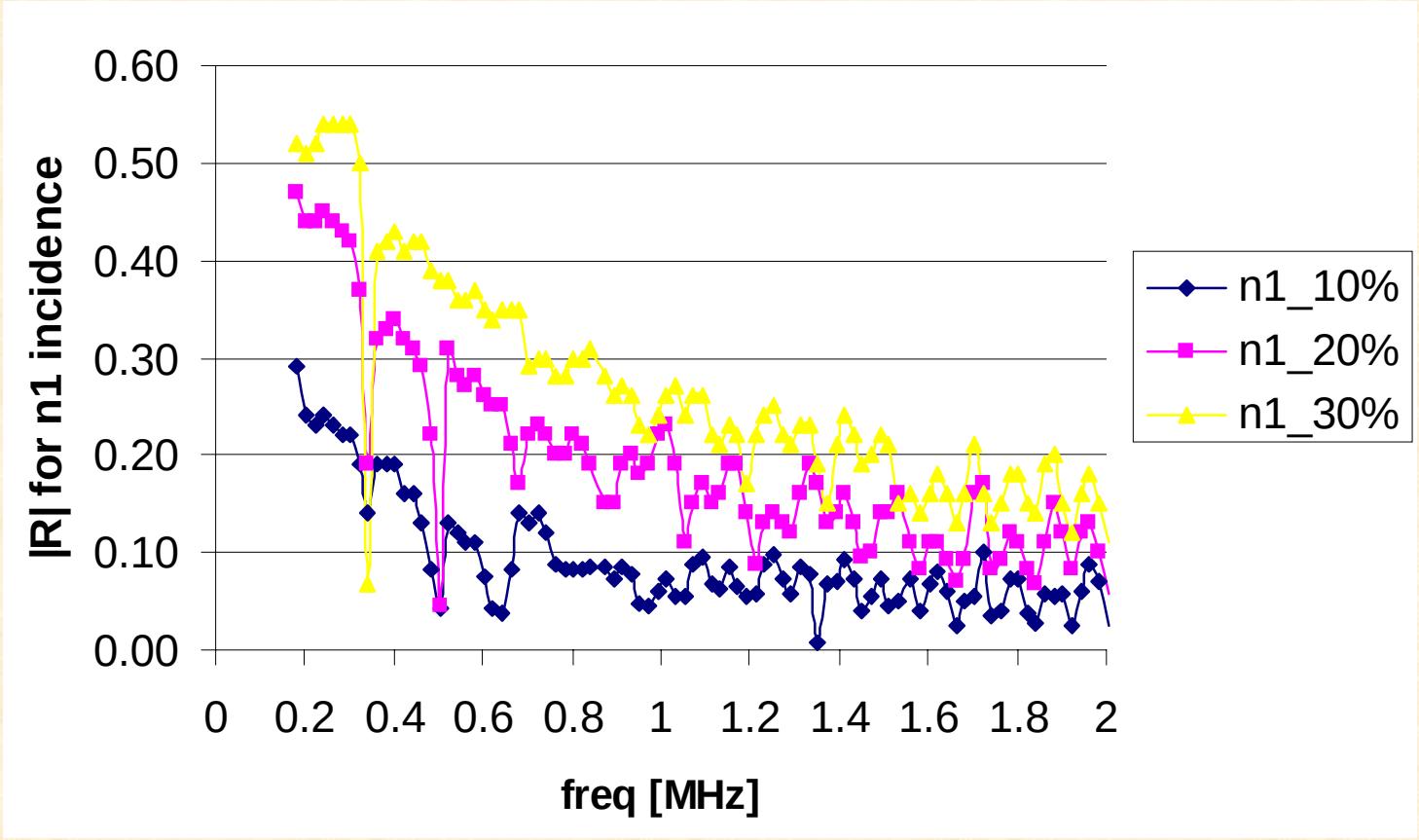
# Flaw Detection

- EMAT horizontal Shear Wave
- 2D and 3D Modeling of the effects of Ultrasonic shear wave on flaws
- Wavelet Analysis
  - Flaw detection
  - Data compression
- Circumferential, Axial,,& SCC flaws, corrosion
- 10” and 12” pipe configurations

# Results of the 2-D modeling

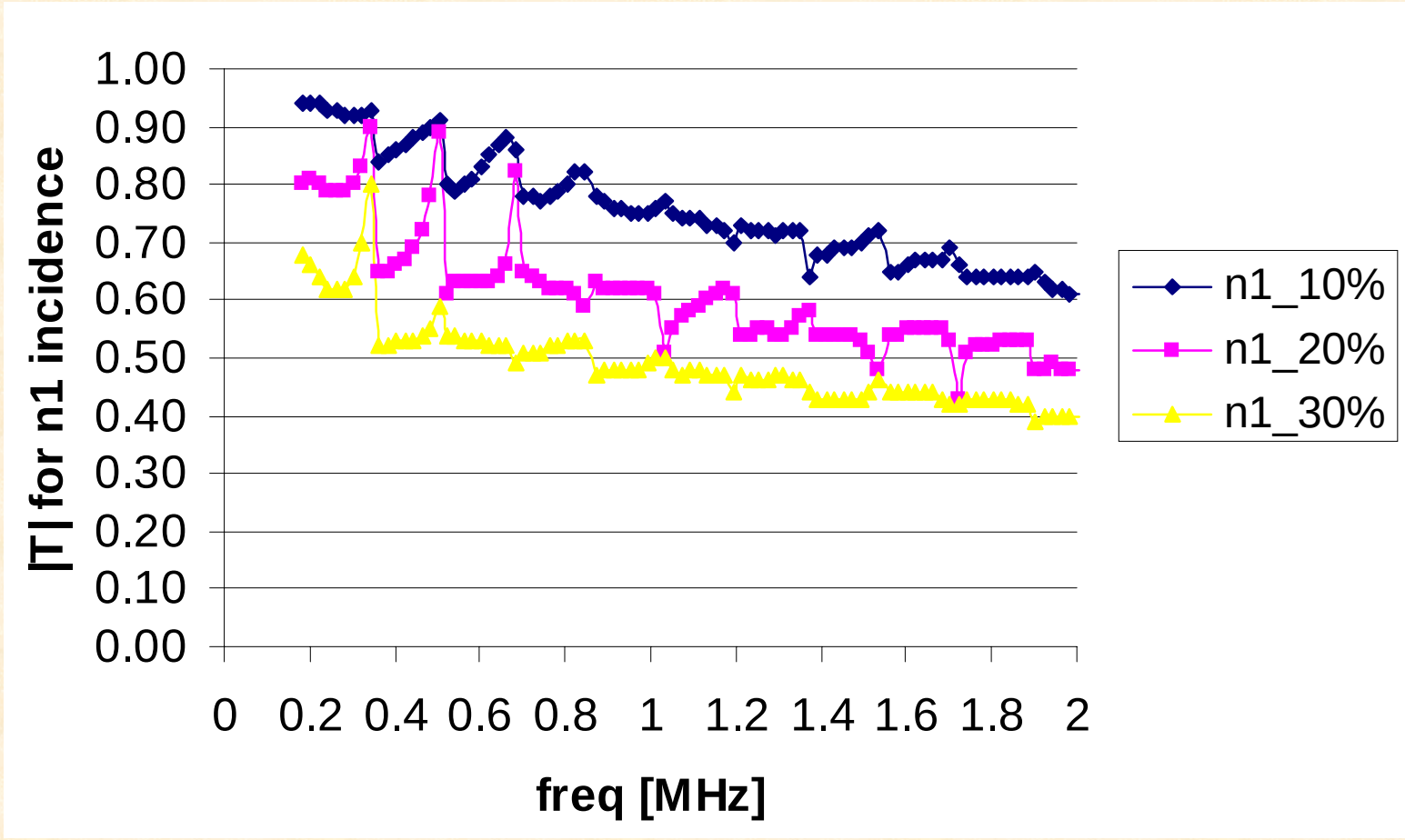
- The n0, n1 and n2 modes occur at 200 KHz,, 260 KHz and 400 KHz
- Large diameter pipes can be modeled as plates
- Approximate velocity of the wave is 3.6 Km/s
- n1 mode is better for detection compared to n0 mode

# Reflection Coefficient for n1 mode



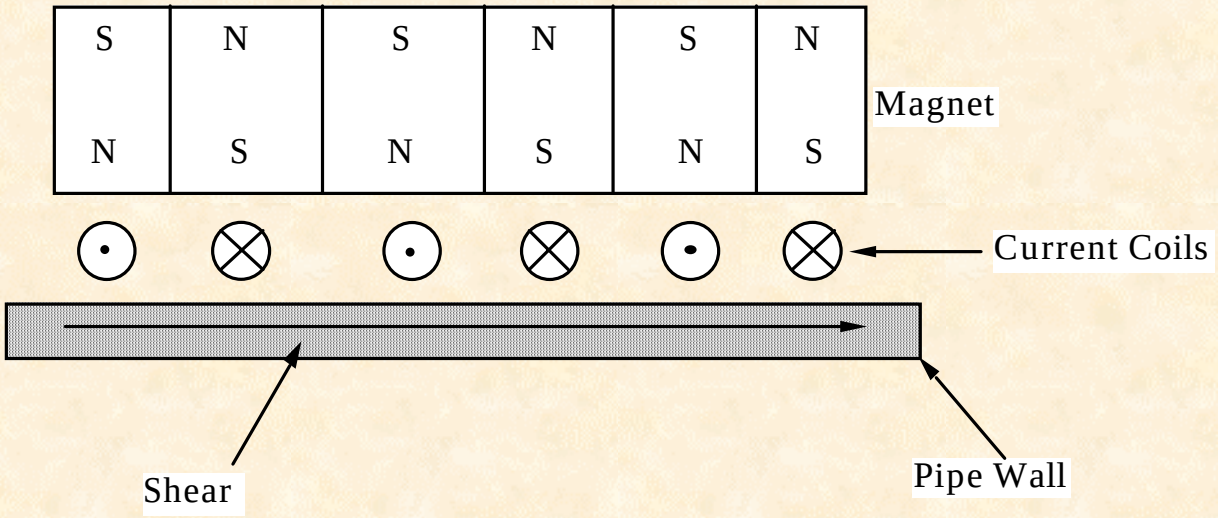

10” diameter Pipe with 1/8” wide defects

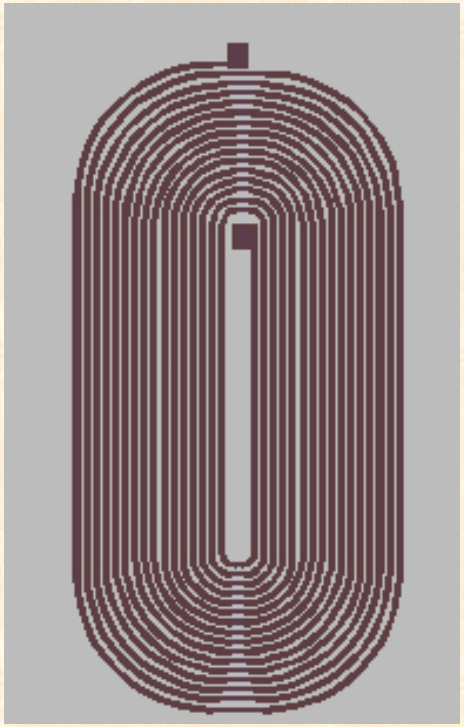
# Transmission coefficient for n1 mode




10” diameter Pipe with 1/8” wide defects

# Shear EMAT



$$\underline{f} = \underline{J} \times \underline{B}$$

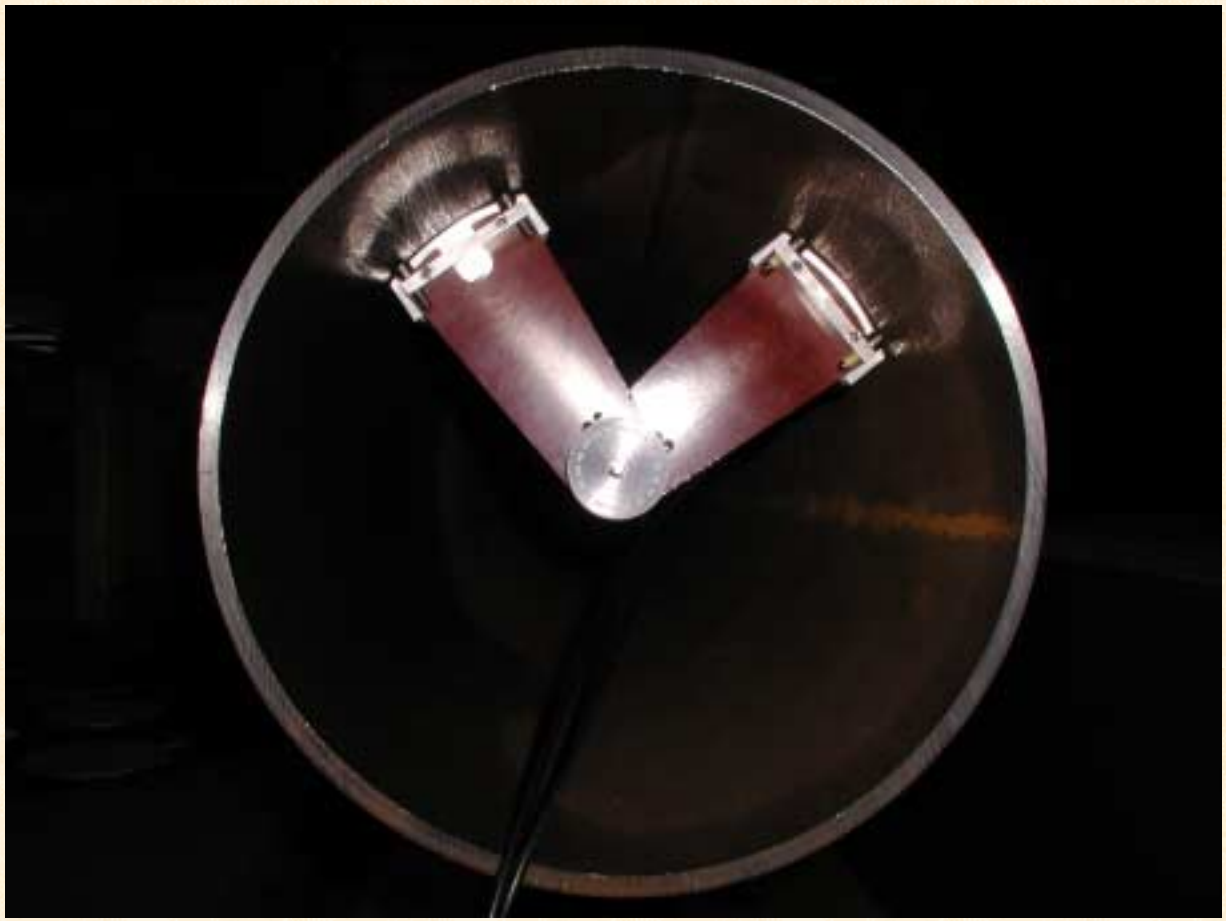
# Experimental set-up

| Flaw | Length | Width | Depth |
|---|---|---|---|
| Longitudinal | 3 | 0.125 | 0.15 |
| | | | 0.175 |
| | | 0.25 | 0.2 |
| | | | 0.225 |
| Circumferential | 3 | 0.125 | 0.15 |
| | | | 0.175 |
| | | 0.25 | 0.20 |
| | | | 0.225 |
| SCC Cracks | 1.5 | 0.006 | 0.1 |

**10” and 12” diameter pipes were used for these experiments**

# Example of a flaw

# Circumferential EMAT Transducer-Receiver



# Axial EMAT Set-up

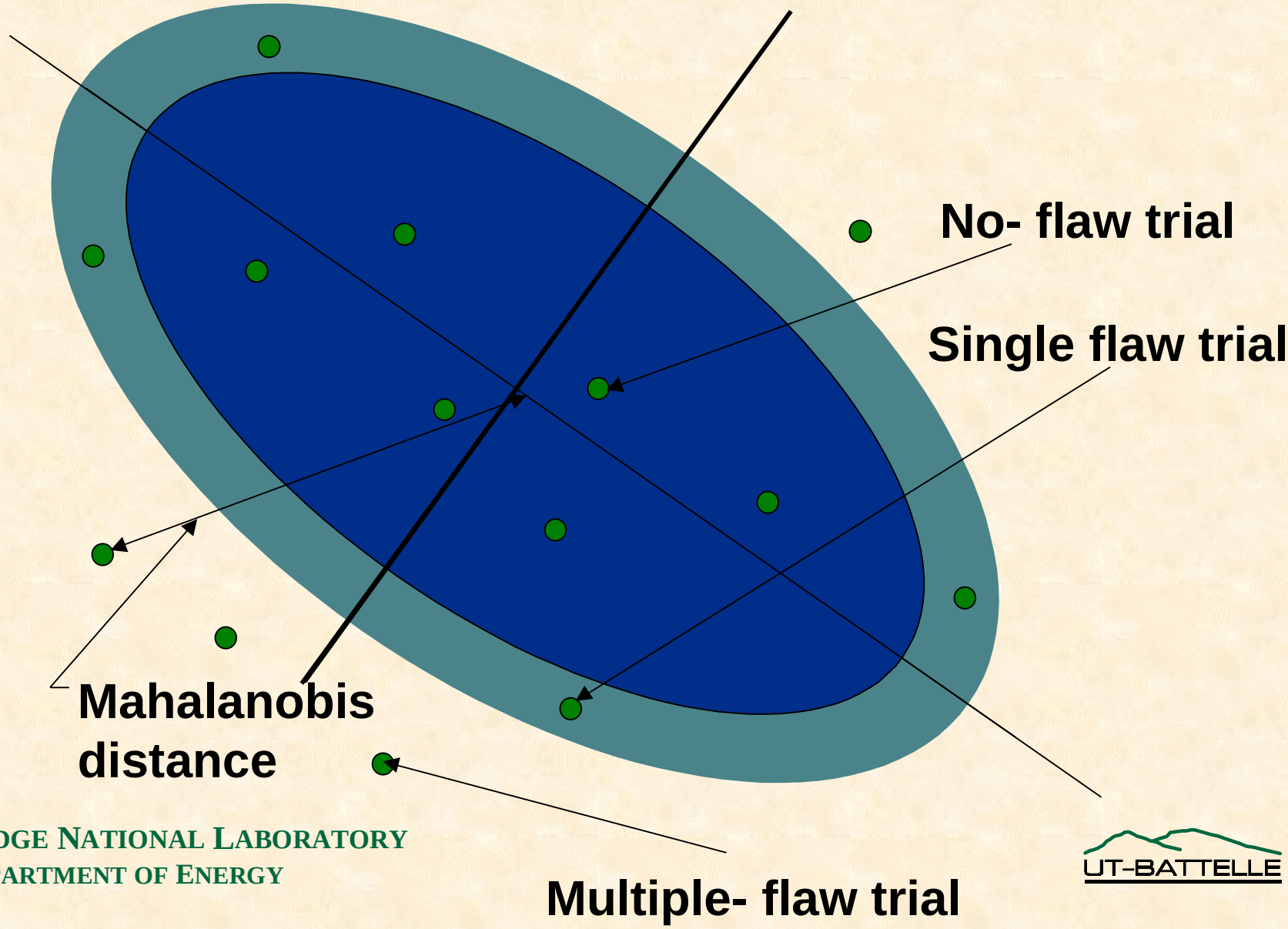
# For a given Trial (EMAT signature) Extract Features

- Take discrete wavelet transform
- Zero out smallest wavelet coefficients until…
  - specified fraction of original energy remains
  - Select several wavelet scales
  - Compute entropies of each scale
- List of entropies is the feature vector

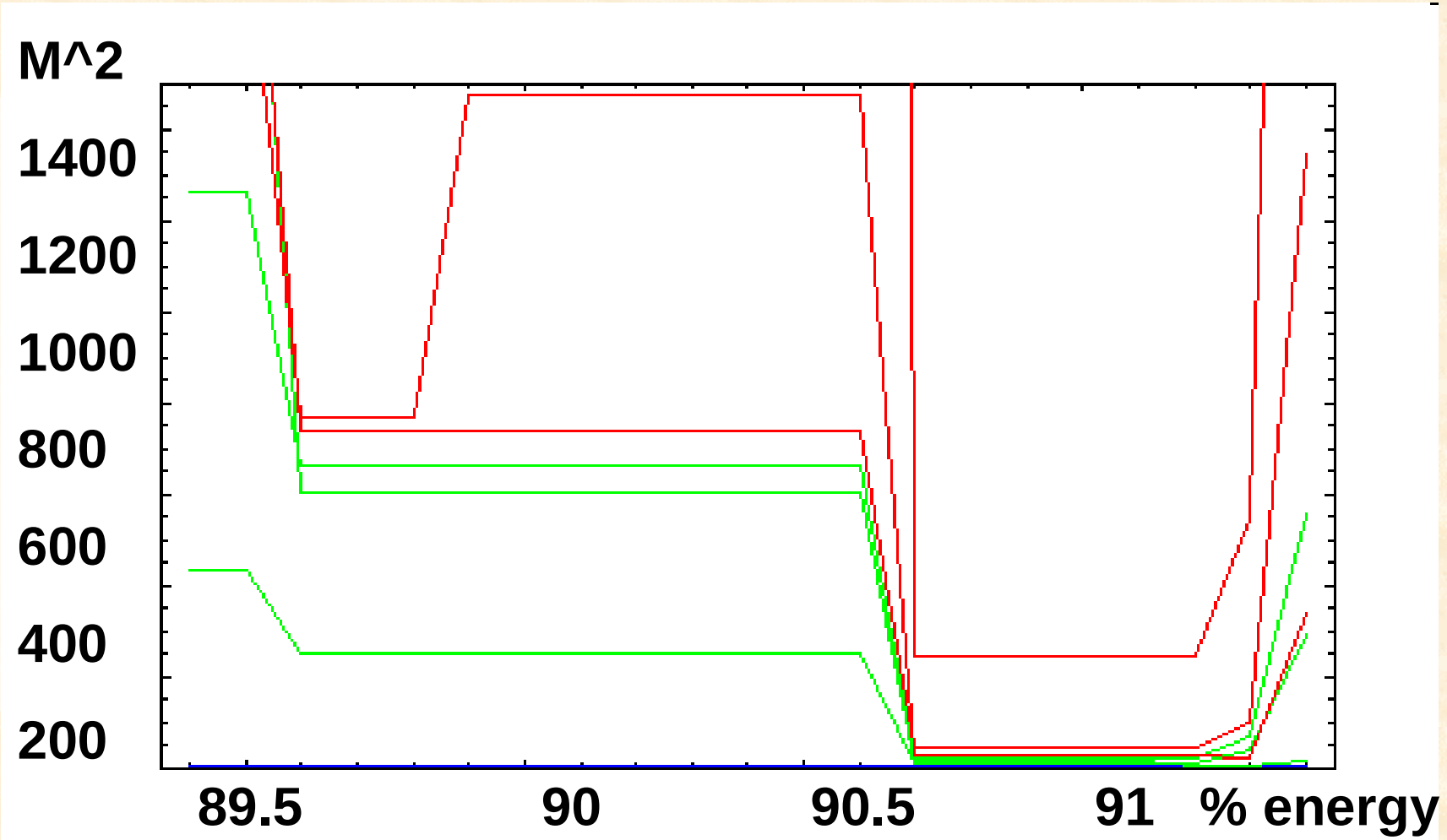
# Repeated trials in “no-flaw” regions produce a tight hyperellipsiodal cluster in feature space

- Cluster center
  - Mean of all “no-flaw” feature vectors
- Orientation of cluster
  - Axes of cluster
  - Eigenvectors of covariance matrix
- Mahalanobis distance
  - Normalized distance from cluster center

The more flawed the pipe, the greater the Mahalanobis distance of the EMAT signature from the no-flaw cluster center

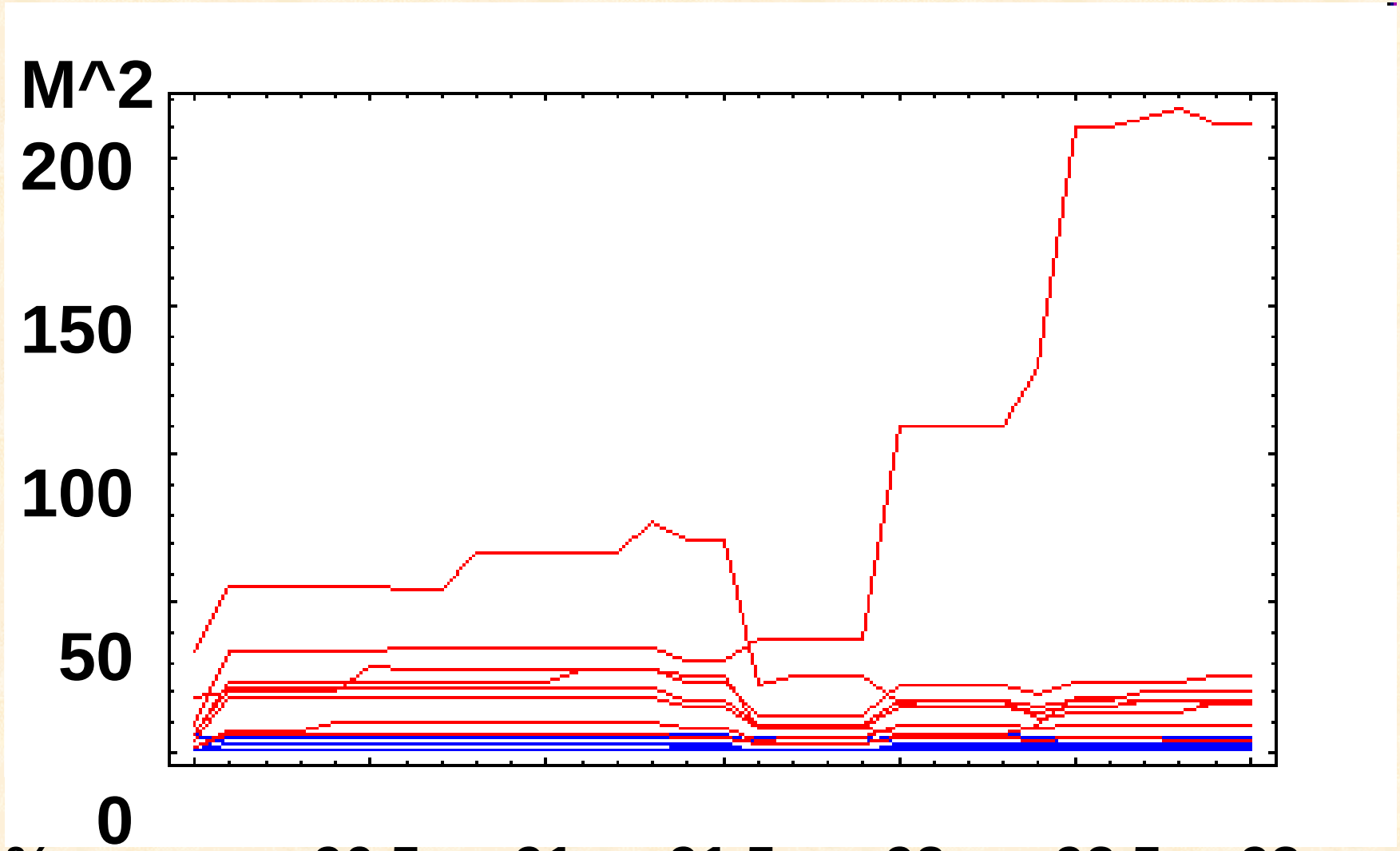


# 10” Pipe 4-D Feature Vector

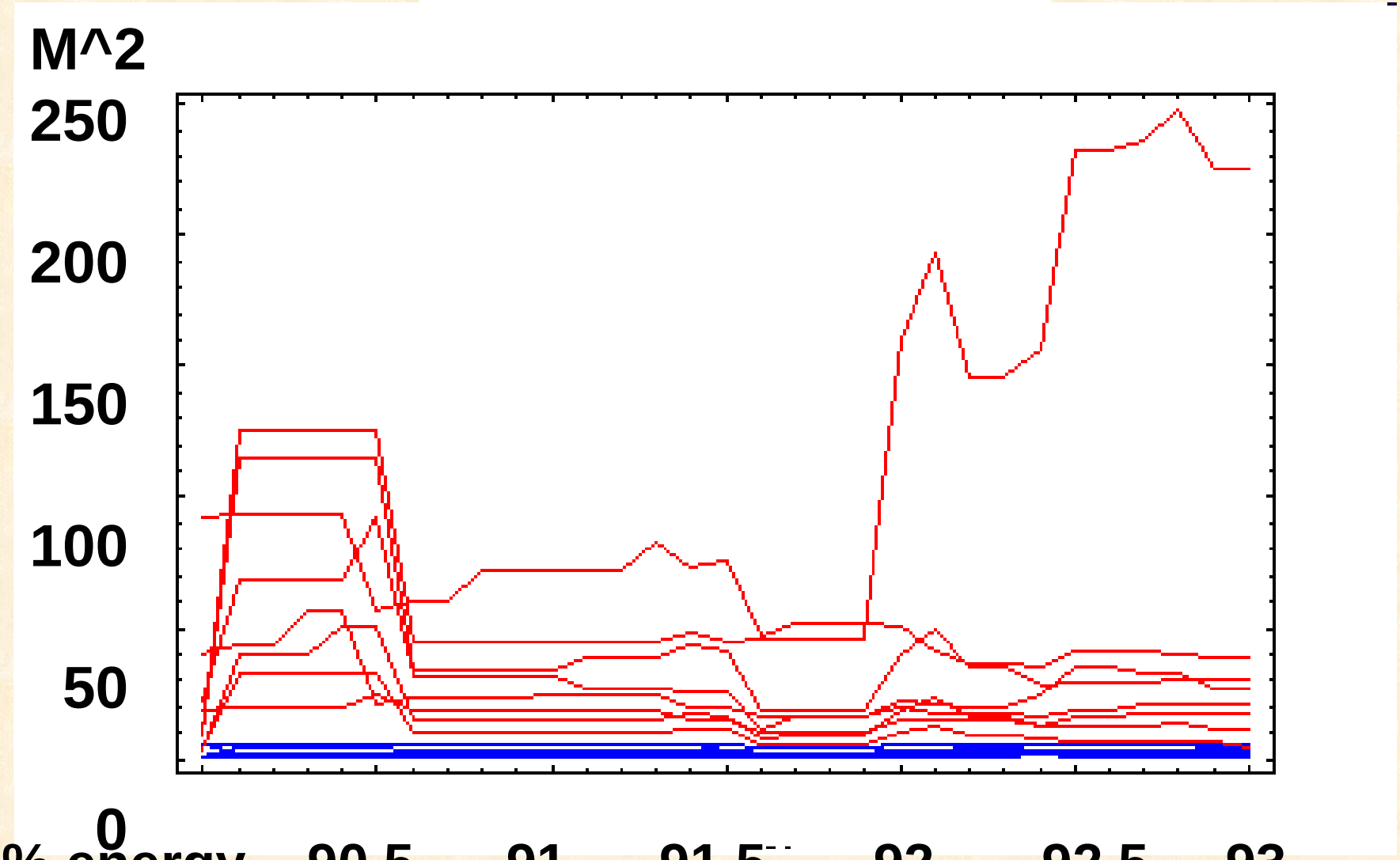



**Blue: No Flaw** **Green: One Flaw** **Red: Multiple Flaws**

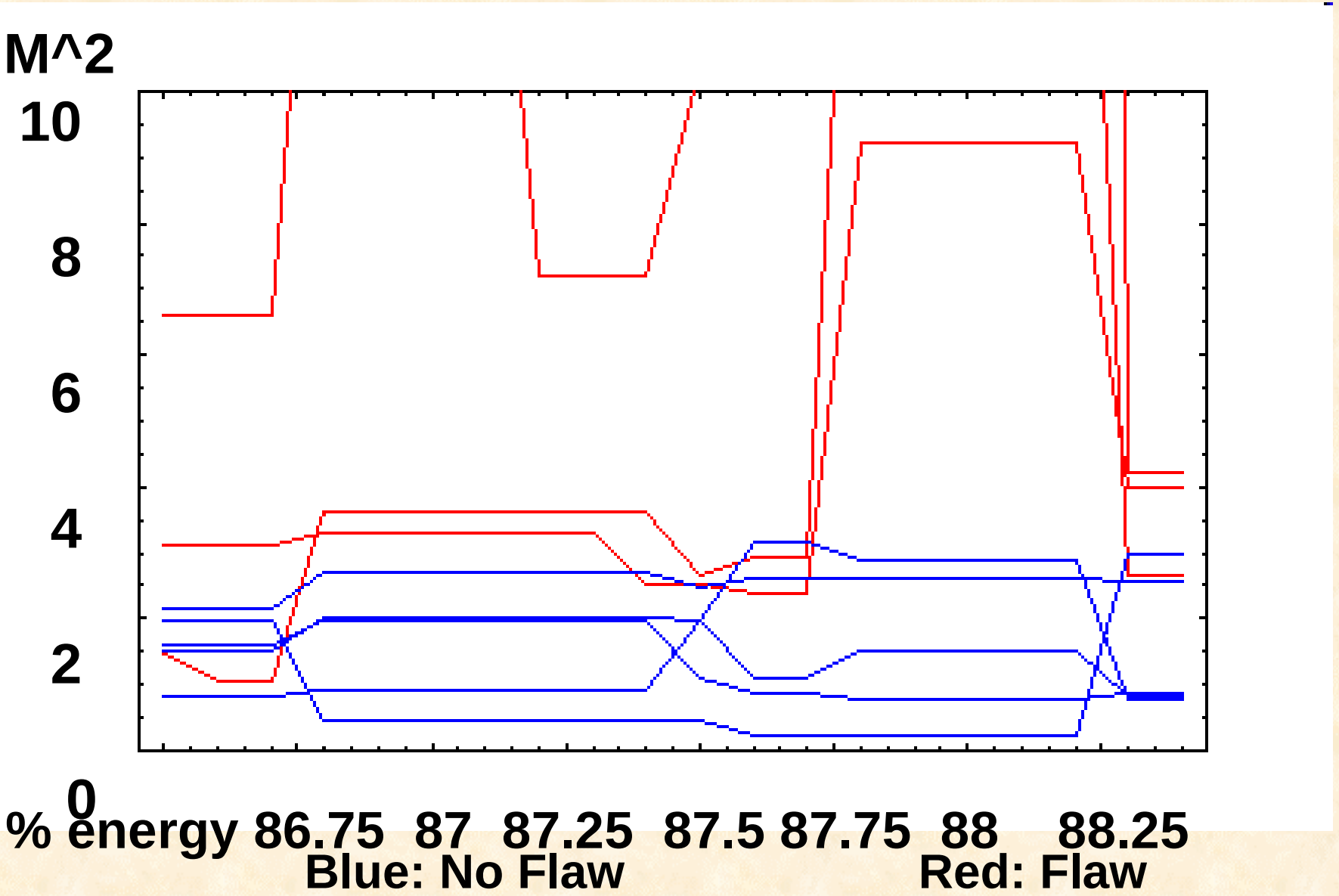
# Axial Flaw Features 12”-Pipe 2-D Feature Vector



# Axial Flaw Features 12”-Pipe 3-D Feature Vector



# Circumferential Flaw Features: 12”-Pipe 3-D Feature Vector



# EMAT Characterization Completed

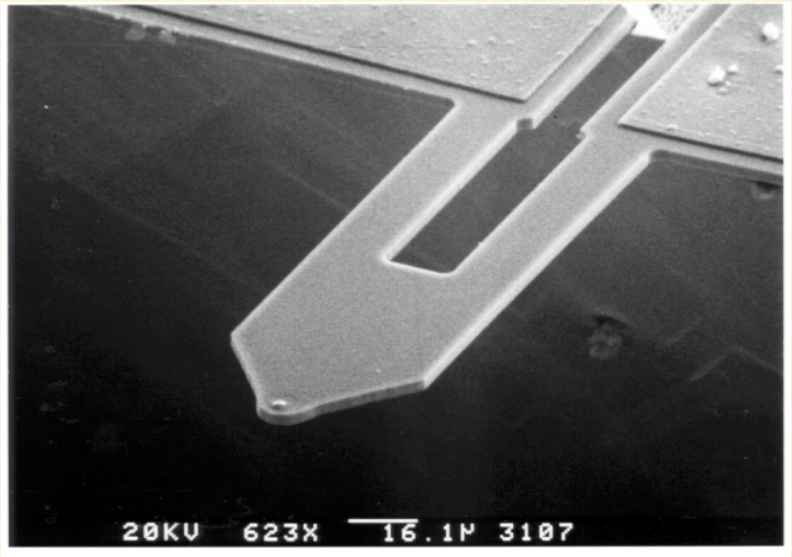
- Determined maximum axial separation of EMATS (circumferential ) --- 3”
- Determine the maximum angular separation of EMATS (axial) --- 35ˆ
- Ability to detect individual flaws
- Obtain characterization capability for metal loss*

# Leak Detection

- To detect existing leaks in pipes using acoustic signal of the gas escaping
- Microcantilever sensor (resonance frequency matching using tunable cantilever)
- Determine range of frequency that leaks produce
- Ability to size the leaks

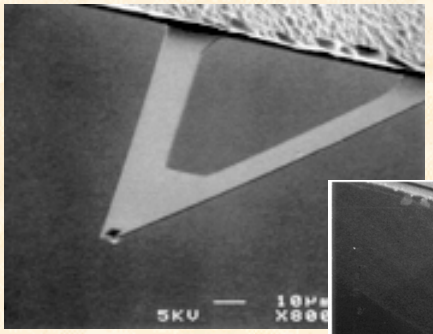
# Microcantilevers

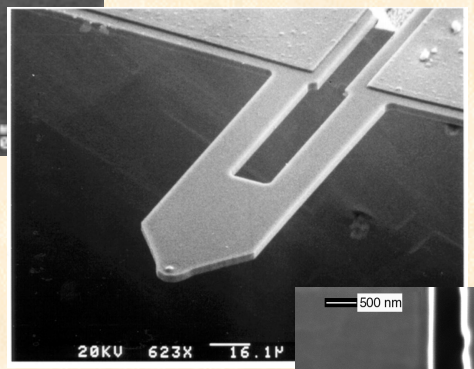
- Dimensions
  - 100 -200 μm length
  - 10-30 μm width
  - 0.3 - 2 μm thickness
- Resonance Frequency
  - 15-45 kHz
- Mass - 10 ng
- Force Constant
  - 0.01 - 3N/m
- Two linearly independent and unique signals in one measurement

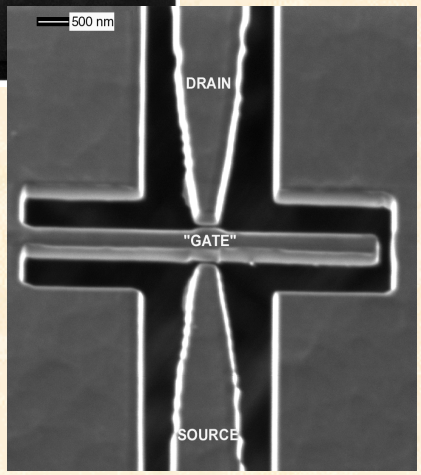


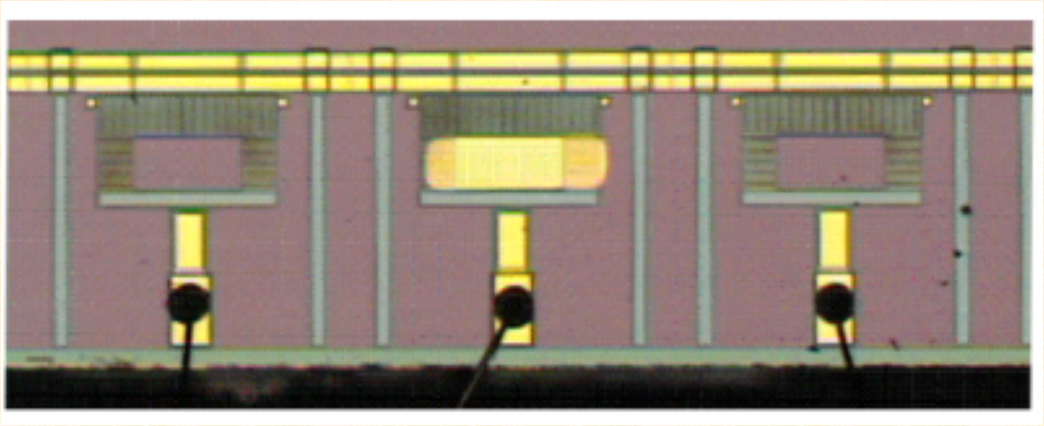
# Microcantilevers: Signal Transduction

- Optical
- Capacitance
- Piezoresistivity
- Piezoelectricity
- Electron Tunneling

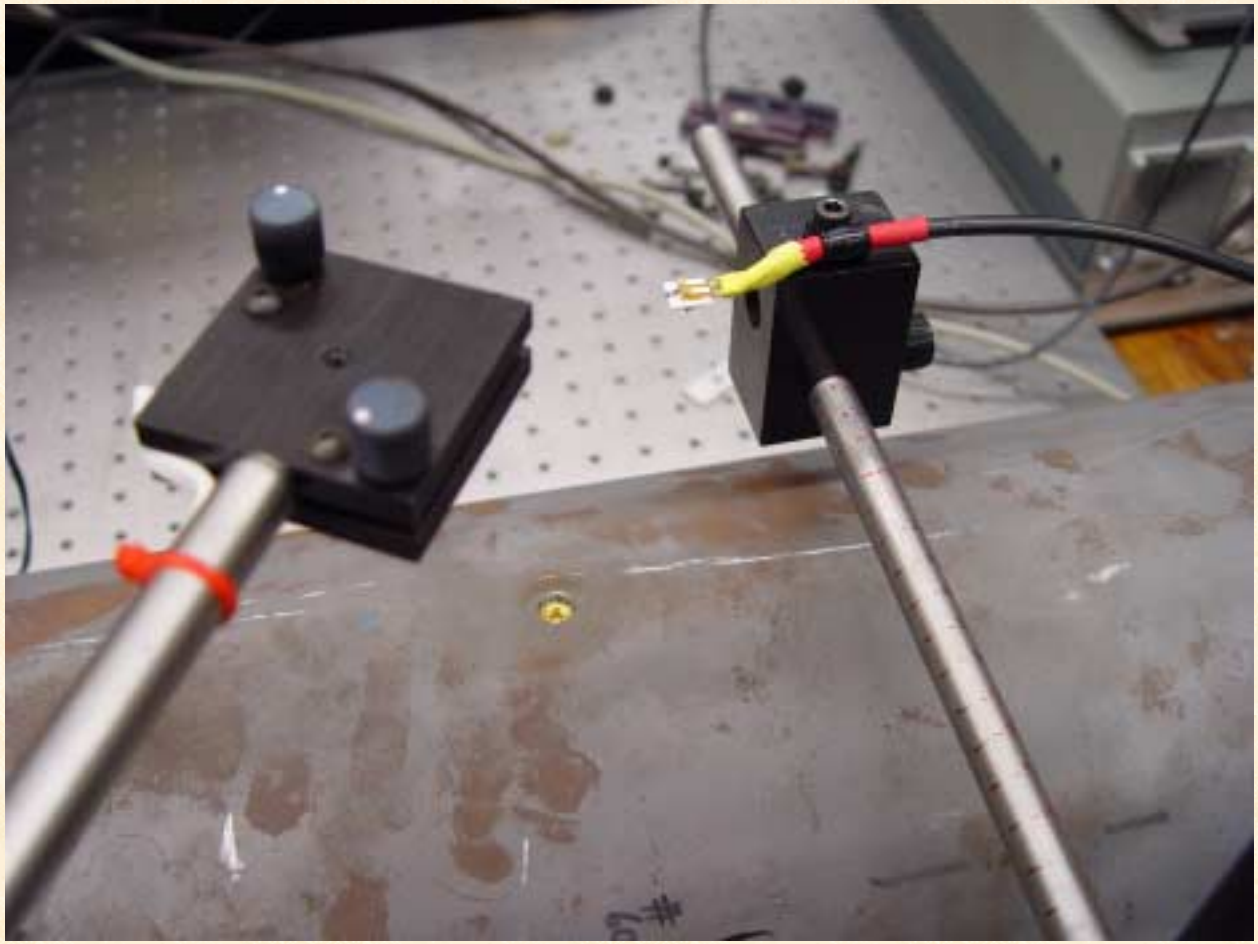


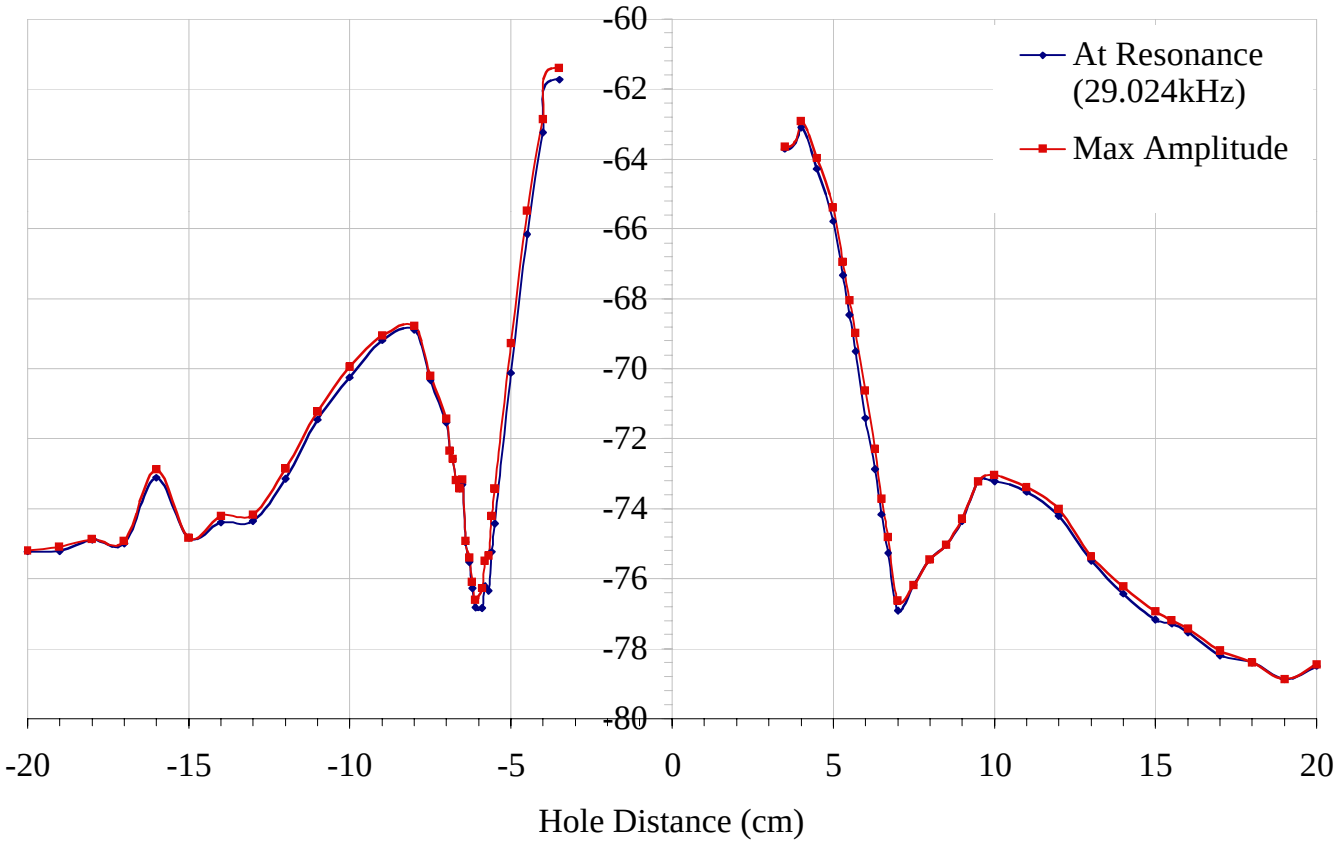



# Experimental Set-up



# Cantilever Response as a function of Distance from Leak



# Goals Till November 2002

- Work towards 3-D modeling of flaws for EMAT signals
- Characterize metal loss
- Characterize leaks using Microcantilever
- Characterize leaks for varying gas pressure and leak size internally

# Future Directions for the research

- Characterize multiple flaws
- Account for the speed of EMAT transducer
- Access the amount of data compression possible
- Tests on pipes taken out-of-commission*
- Optimization of the design
- Develop prototype cantilever sensor for leak detection

# Future Directions for the research cont..

- Integrate insight obtained from 3D modeling of flaws
- Integrate the system for field deployment